Station Keeping with an Autonomous Underwater Glider Using a Predictive Model of Ocean Currents

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Motivation

- Study water column at single geographic location
- Traditional Mooring
  - Cable and surface buoy anchored to seafloor with sensors attached
  - M1 Mooring has 2.55 km radius watch circle, it is often within 1.5 km
  - Expensive
- Virtual Mooring
  - Station keeping, profiling autonomous underwater vehicle
  - Can follow circuit near the target location instead of maintaining fixed location
  - Inexpensive

Surface Water and Ocean Topography (SWOT) Mission

Calibration and Validation

- Measuring sea surface height
- Ground truth data is needed to calibrate SWOT data
    - Baseline of 20 data points
- Classical way to do this is install moorings
- Use autonomous marine robots as “virtual moorings” instead?

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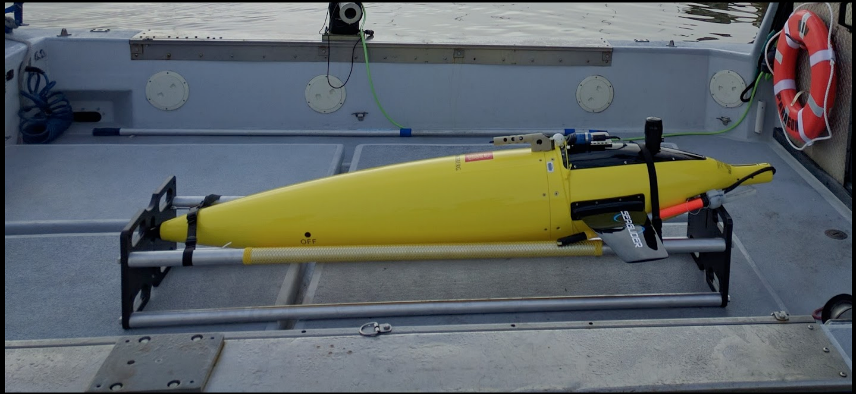
Underwater Gliders

- Underwater Glider: motion via variable buoyancy engine
- Yo-yo dives gather data at depth, transmit science data and GPS fix at surface
- Extremely efficient → long duration operations up to ~10,000 km
- Limited control authority, can be overpowered by currents
  - Nominal Glider Speed: 0.20 - 0.35 m/s
  - Nominal Current Speed: 0.0 - 1.0 m/s

Underwater Gliders in This Study

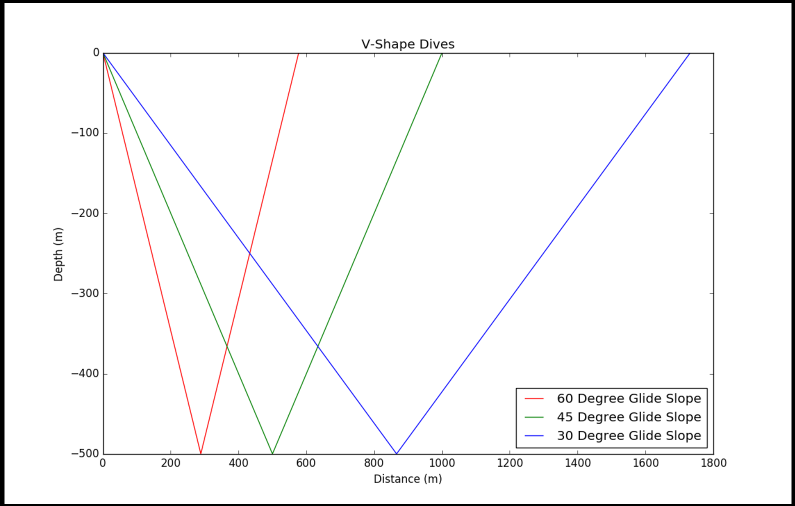
Kongsberg Seaglider

- Length: 2 meters
- Wingspan: 1 meter
- Weight: 52 kilograms
- Maximum Depth: 1000 meters
- Typical Speed: 0.25 m/s

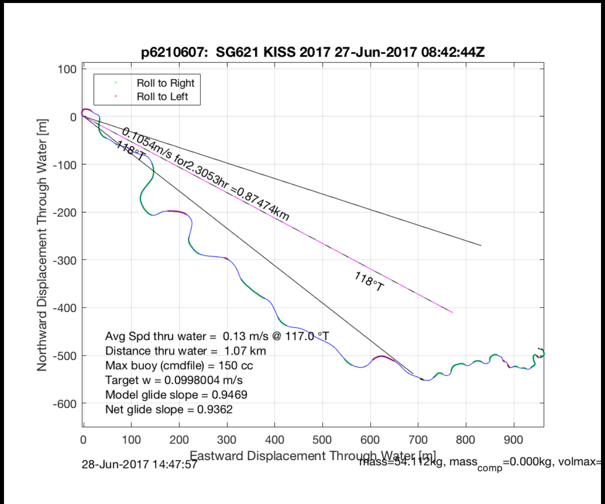


Seaglider Dive Profile

Planned



Actual



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Autonomous Path Planning

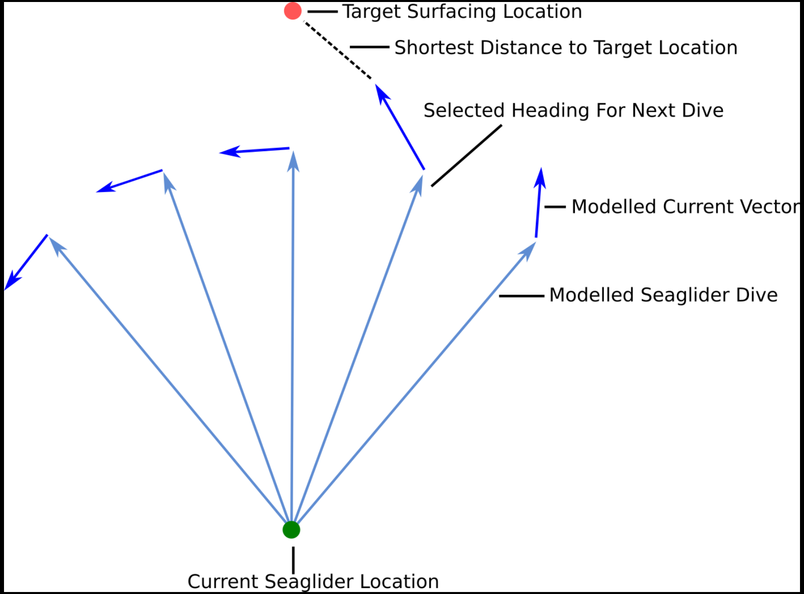
Baseline

- At each surfacing, set heading toward target
- Maintain single heading for full dive

Predictive Control

- At each surfacing, receive latest GPS fix, simulate possible trajectories accounting for currents, send best parameters to vehicle
- Potential controlled parameters
  - Dive profile, heading, glide slope, depth
- ~300 possible trajectories if using all parameters

Autonomous Path Planning



Predictive Control

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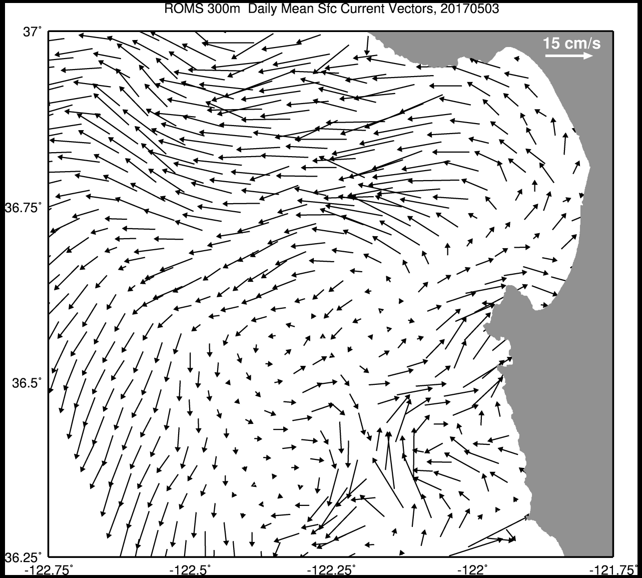
Predicting Ocean Currents

Regional Ocean Modeling System (ROMS)

- ROMS is a discrete, cell-based predictive model of the ocean
  - Temperature, salinity, sea surface height, ***currents***…
  - Data assimilation from multiple sensor sources
- Our ROMS Model
  - Horizontal Resolution: 300 meters
  - Vertical Resolution: 24 non-uniformly spaced depths
  - Temporal Resolution: 1 hour
  - Daily 72 hour forecast



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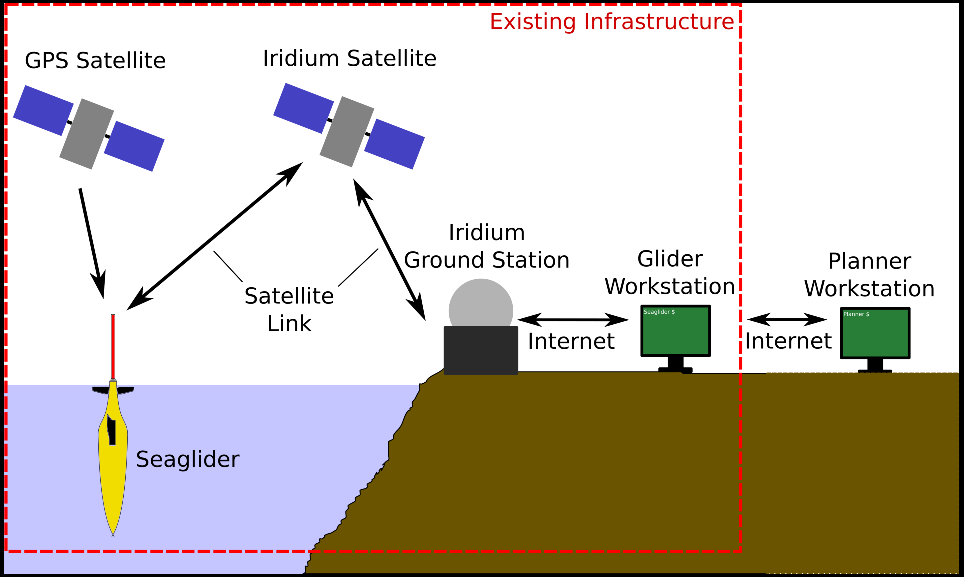
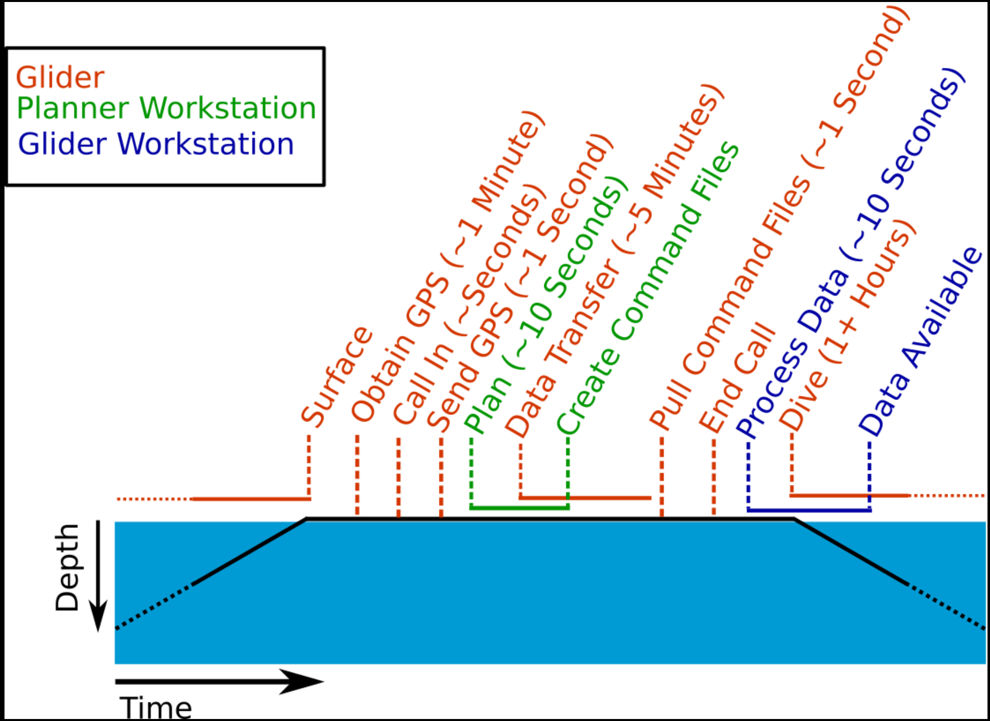
Glider Control



Glider Nominal Timeline



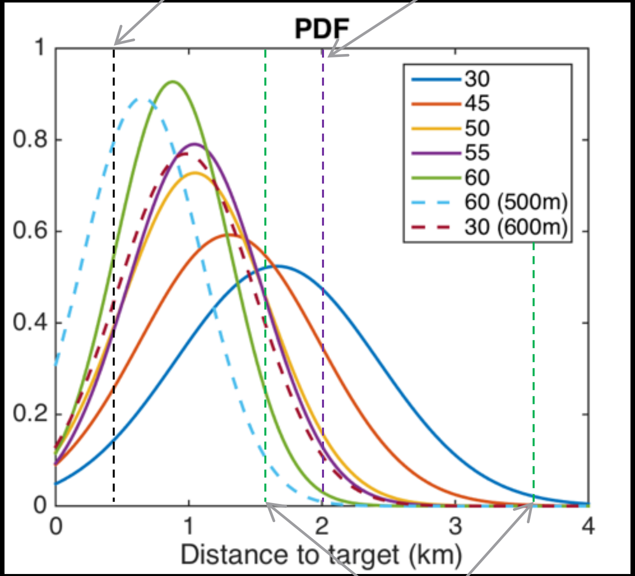
October 2016 Deployment

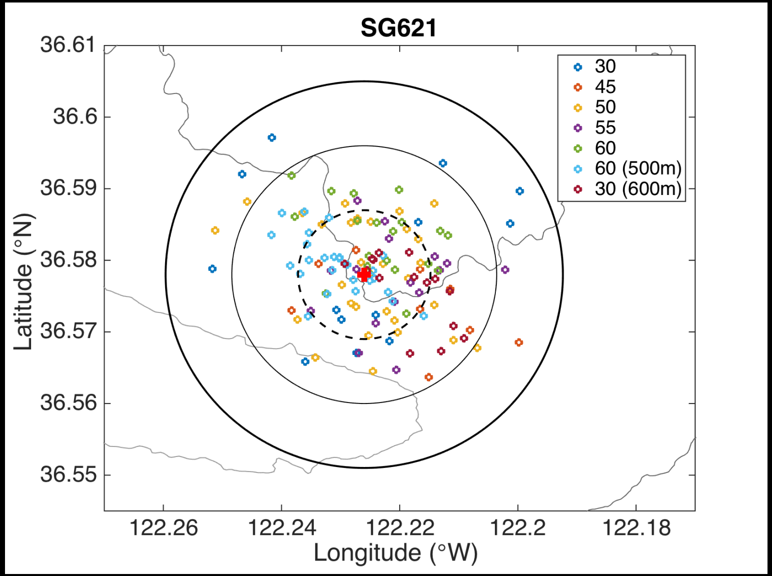
- Planner controlled parameters
  - Heading
- Manually varied parameters
  - Glide slope
  - Dive depth

October 2016 Deployment Results

Average M1 mooring error over 4 weeks

[Hodges and Fratantoni 2009]

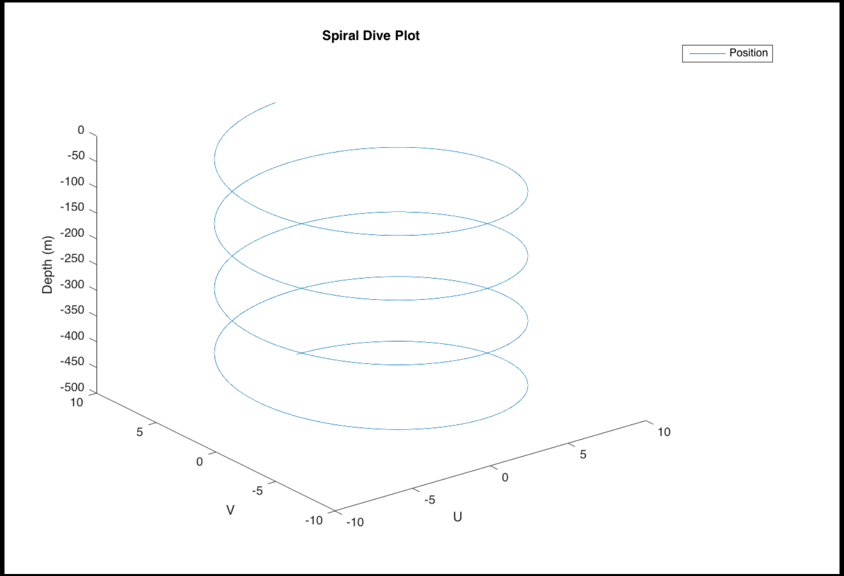


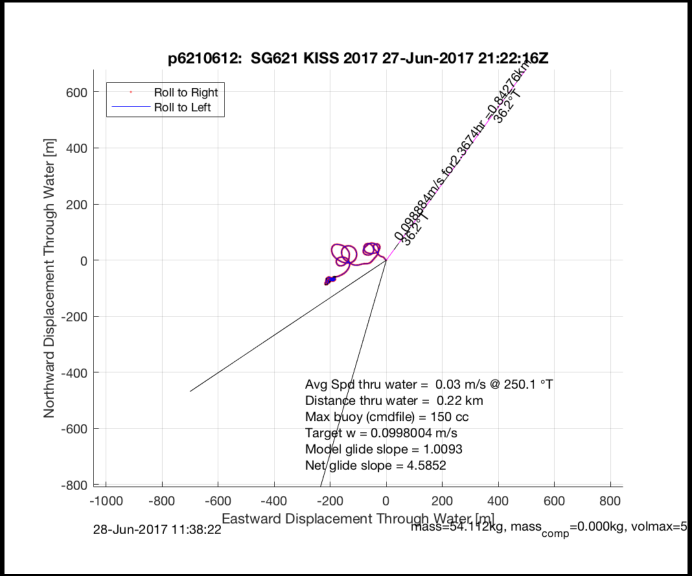


[Rudnick, Johnston, and Sherman 2013]

Future Work

Seaglider Helix Dive



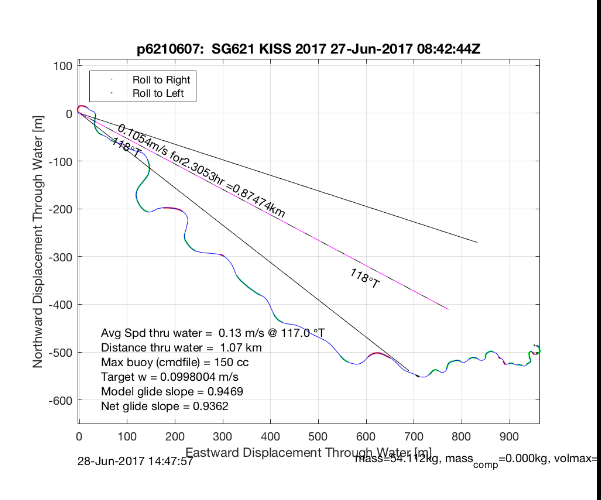


Seaglider Dive Profiles

Path Through Water

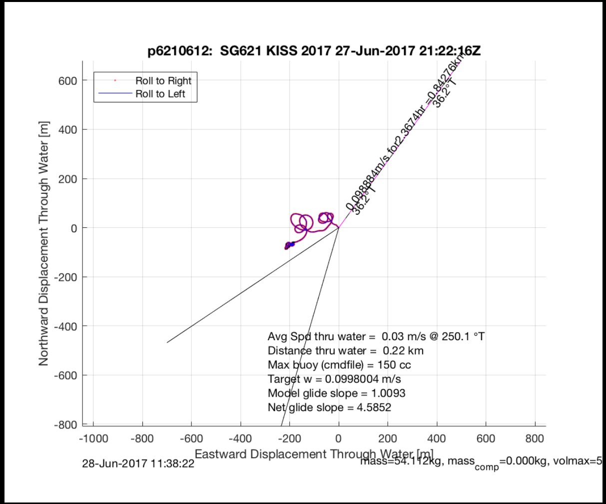
V-Dive

Long distance travelled



Helix Dive

Short distance travelled



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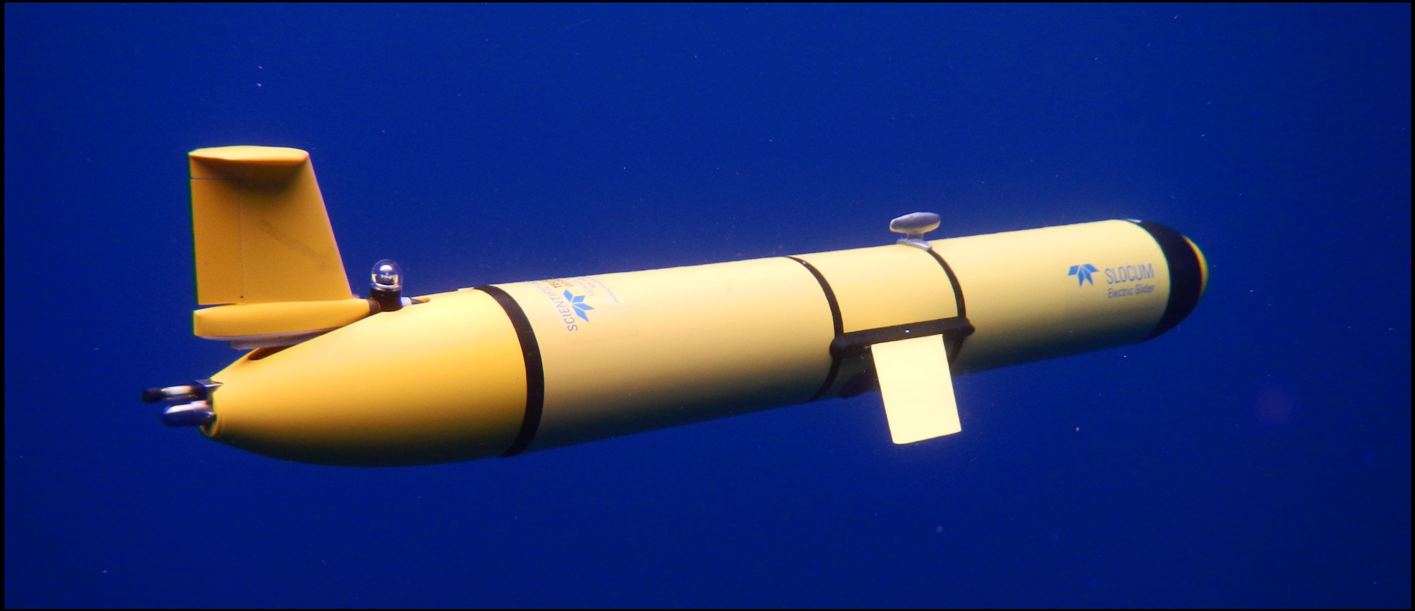
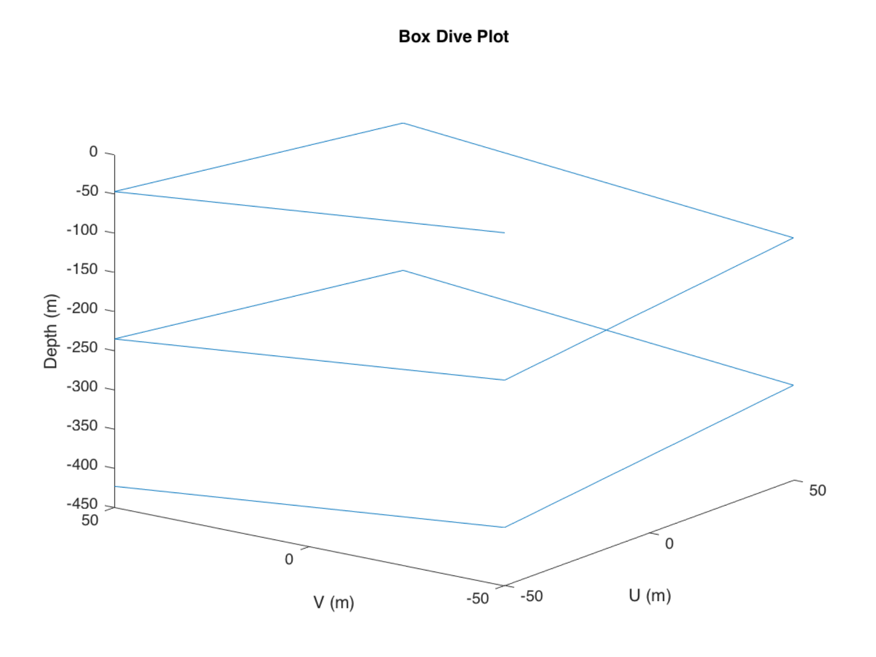
Teledyne Slocum



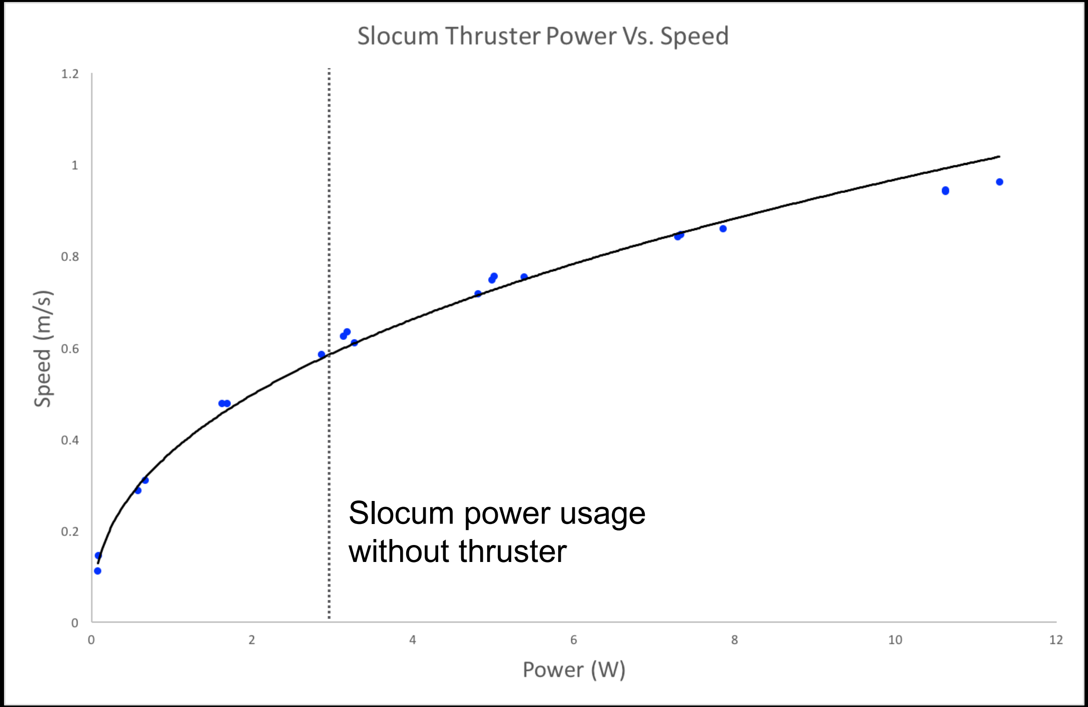
Multi-Waypoint Dives

- Slocum gliders allow for multiple waypoints per dive
- Enables heading changes underwater
- Potential candidate for non-greedy search strategy
    - High current variability with depth
    - No re-planning underwater
    - Search space too large for exhaustive search



Hybrid Glider

- Optional thruster attachment
- Slocum thruster allows for periodic speed boosts up to 1 m/s
- Useful in areas with stronger current



Future Work

- Commanding Slocum gliders
  - Thruster usage
  - Multi-Waypoint commanding
- Investigate non-greedy search strategies
- More deployment time
  - Controlling all glider dive parameters (June-July 2017)
  - SWOT crossover point or other similar location
  - Direct comparison between strategies

Related Work

- B. A. Hodges and D. M. Fratantoni JGR 2009 - station keeping using autonomous underwater gliders
- D. L. Rudnick, T. M. S. Johnston, J. T. Sherman JGR 2013 - station keeping using autonomous underwater gliders
- M. Troesch et al. ICAPS 2016 – station keeping using vertically profiling floats
- M. Troesch et al. PlanRob (ICAPS 2016) – station keeping using vertically profiling floats with analysis of ROMS models

Conclusion

- Virtual moorings via underwater gliders show promise as a replacement for traditional moorings in some cases.

- We developed an approach to dynamically modify dive parameters of an underwater glider in order to station keep.

- We conducted a deployment in October 2016 off the coast of Monterey, California in which we were able to station keep with error under 1 km.

- More deployments are necessary to better understand the performance of the algorithm presented.

Acknowledgments

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